Application of Optically Detected Magnetic Resonance in a Nanoprobe to Measurement of Single Electron and Nuclear Spin States

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Progress in nanotechnology, including spintronics and quantum information processing based on a solid-state quantum computer, has brought significant attention to the problem of measurements of single electron and nuclear spin states. Here we suggest a novel approach for measurement of single electron and nuclear spin states. The novel aspects of our approach are: 1) use of a nanoprobe for the optically detected magnetic resonance (OMDR), 2) nondestruction of the spin state being measured, 3) nanoscale spatial resolution, and 4) high sensitivity of ODMR to a single electron or nuclear spin orientation relative to an external magnetic field. Our modified ODMR approach consists of an AFM with a photoluminescent material (nanoparticle) located at the apex of an AFM tip (see Fig. 1), which exhibits ODMR in the vicinity of an unpaired electron or nuclear spin in the sample. This approach transfers the detection of electron magnetic resonance from a microwave frequency domain to an optical domain, which significantly increases measurement sensitivity.

In this method, the nanoparticle is excited from its ground state 1 into the first excited state 2 by absorption from a laser field, and subsequently decays through nonradiative transitions to magnetic sublevel states 3. (See Fig. 2.) An external magnetic field lifts the degeneracy of the triplet states and changes the energy splitting between these magnetic sublevels as well as their populations and lifetimes. Resonance is achieved by scanning the magnetic field from a nearby radio-frequency coil to induce transitions between these magnetic sublevels to change their relative populations, thus increasing or decreasing the intensity of specific peaks in the photoluminescence spectrum resulting from decay back to the ground state. Nanoprobe absorption in an evanescent laser field could be significantly enhanced when placed at the apex of a sharp silicon tip. The potential resolution of this method is related to the size of the photoluminescent probe, typically 1–10 nm. One of the most promising applications is the nondestructive measurement of a qubit single spin state in a quantum computer.

Measurement of a single electron spin state. Our preliminary analysis of the dependence of the sensitivity on geometry shows that at optimal conditions the ODMR of a nanosize probe can sense the magnetic field of a single electron spin [1].

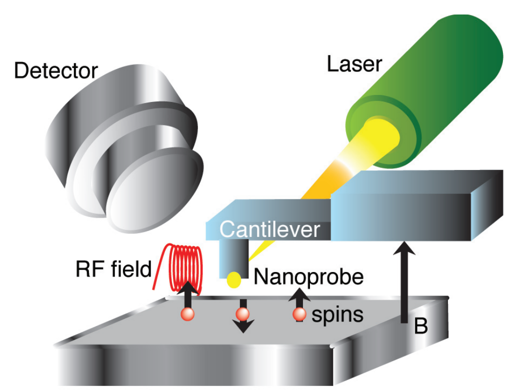

Fig. 1. AFM-ODMR setup.

Measurement of a single nuclear spin state. We consider the two states of a single nuclear spin of an impurity atom with an electron inside the solid-state matrix (Fig. 3). The scheme of energy levels of electron-nuclear spin states in the permanent magnetic field is presented by Fig. 4. The energy levels of an electron spin have a shift due to hyperfine interaction that depends on the state of a nuclear spin. To measure the state of the nuclear spin, we exploit the fact that the electron spin resonance with transition frequency between sublevels of the electron spin depends on the state of the nuclear spin (see Fig. 4). Thus, for example, the RF field will selectively induce transitions only between the states $<S_e= -1/2, I_n = 1/2 \mid$ and $< S_e = 1/2, I_n = 1/2 \mid$ (blue arrow in Fig. 4), and will not interact with the transition $<S_e = -1/2, I_n = -1/2 \mid - < S_e = 1/2, I_n = -1/2$ (red arrow in Fig. 4). Finally, the two electron spin states involved in the transitions correspond to the same nuclear spin "up" state. Therefore, the proposed measurement procedure does not change the state of a nuclear spin, and realizes a nondestructive measurement of a nuclear spin state.

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[1] B.M. Chernobrod and G.P. Berman, *J. Appl. Phys.* **97**, 014903 (2005).

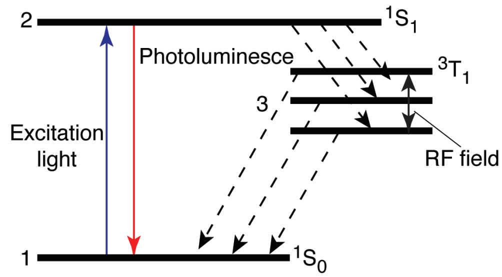

Fig. 2. Transitions in the nanoparticle.

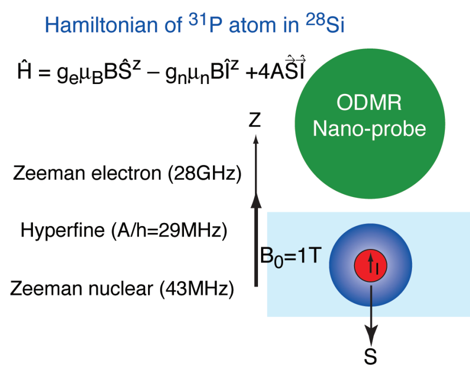

Fig. 3. Nanoprobe and ^{31}P atom in ^{28}Si matrix. Relevant energies are shown at left.

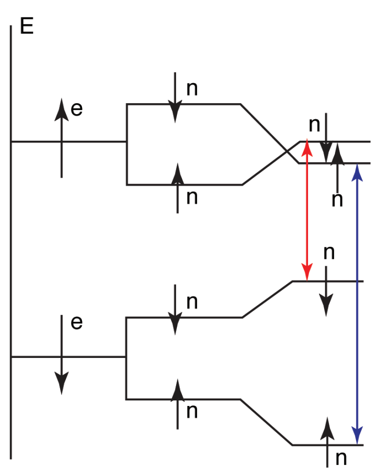

Fig. 4. Hyperfine structure of electron-nuclear spin energy levels.